Effect of Temperature and Salinity on the Survival of Young Atlantic Menhaden, *Brevoortia tyrannus*

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ABSTRACT

Survival of young Atlantic menhaden at different salinities and temperatures was studied in the laboratory. Fish were tested in the spring, summer, and early fall at high temperatures (25 to 36 C) and low (5 to 7‰), intermediate (15‰), and high salinities (31 to 34‰). In the late fall and early winter, tests were conducted at temperatures of 3 to 7 C and salinities of 10 and 26 to 30‰. Temperature had the greatest effect on survival; acclimation time also affected survival but to a lesser degree. Salinity did not appear to markedly affect survival time at the temperatures studied. Yearlings were more sensitive to high temperatures than were younger fish.

INTRODUCTION

Investigation of the response of young Atlantic menhaden to different levels of environmental factors forms one phase of research at the Bureau of Commercial Fisheries Biological Laboratory in Beaufort, North Carolina. Extremes in temperature and salinity encountered in estuarine waters probably contribute to natural mortality in menhaden populations and may be conjectured as being at least partly responsible for fluctuations in year-class strength. Temperature and salinity probably also affect the distribution of young menhaden within an estuary. In some estuaries avoidance of adversely high water temperatures by fish and shellfish is becoming increasingly difficult as industry discharges increasingly greater volumes of heated waste water (Mihursky and Kennedy, 1966).

A series of laboratory experiments was begun in the spring of 1966 to determine whether high or low water temperatures, salinity, and their interaction materially affect the survival of young menhaden. Field records suggested that menhaden collected in South Carolina estuaries withstood 36 C water temperatures. Salinities of the nursery areas for young menhaden vary from 0 to 40‰. In this study we tried to simulate the upper (or lower) ranges of temperature and salinity to which young menhaden might be exposed in their natural environment. For example, in the late spring and summer when water temperatures are fairly high, we tested fish at temperatures of 25 C or greater; in the late fall when water temperatures drop rapidly, tests were conducted at 7 C and below. In addition, we examined the effects of (1) acclimation time, (2) rate of change from acclimation temperature to test temperature, (3) oxygen concentration, and (4) the effect of a common parasite on the gills. The present work follows earlier studies of the tolerance by larval Atlantic menhaden to low temperatures at different salinities (Lewis, 1965 and 1966).

EXPERIMENTAL MATERIAL AND PROCEDURES

Young menhaden were collected as needed in the vicinity of Beaufort, North Carolina. Young-of-the-year were collected in a small pound net and with a haul seine from the lower Neuse River (a low-salinity area) and yearlings with a haul seine from Broad Creek (a high-salinity area). The young-of-the-year ranged from 33 to 109 mm and yearlings from 138 to 194 mm total length. The fish were transported to the laboratory in a 125-gallon tank. As the trip took less than 1 hour the water was not aerated or recirculated. At the laboratory, fish were placed in an acclimation tank with continuous flowing water and held at least 3 to 4 days until handling mortality subsided. All water used to acclimate or test the fish was pumped from the Beaufort Harbor. When we needed lower salinity water, fresh water from the laboratory well was added to dilute the harbor water.

The experimental layout consisted of a 600-gallon, circular fiberglass acclimation tank and three, 25-gallon, plastic-lined metal

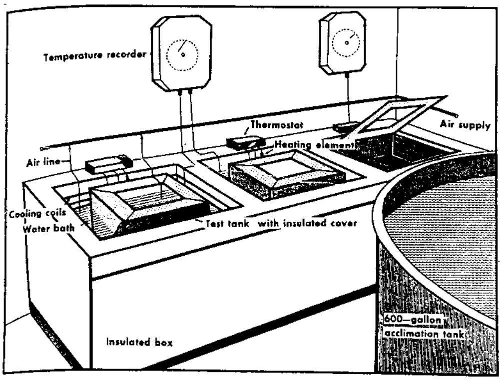

FIGURE 1.—Experimental layout for the study of the effects of temperature and salinity on young menhaden.

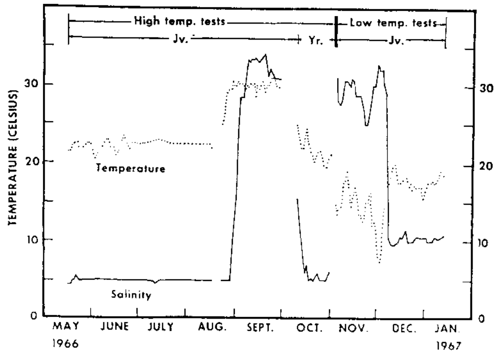

FIGURE 2.—Temperatures (dotted line) and salinities (solid line) of water in the tank at which young-of-the-year and yearling Atlantic menhaden were acclimated during experiments.

test tanks (Figure 1). A Thermistemp and thermistor probe made by Yellow Springs Instrument Company[1] regulated the temperature in each test tank. During acclimation, fish were fed a powdered fish ration or *Artemia* nauplii. Feeding continued during a test as long as the test fish accepted food.

As we had no prior knowledge of the upper lethal temperatures for young-of-the-year Atlantic menhaden, we ran preliminary tests to determine at what temperature stress occurs. Fish were acclimated at least 1 week to temperatures of 20 to 23 C and then tested at 25, 30, and 35 C. Salinity of acclimation and test waters was about 5‰. No significant mortality occurred at 25 or 30 C, but all fish died in less than 15 hours at 35 C.

Additional tests were run at 5‰ salinity and temperatures of 32, 33, and 34 C, levels commonly observed during the summer in estuarine areas known to harbor concentrations of young menhaden. No significant mortality occurred at 32 or 33 C, but at 34 C 50% of the test fish died within 5 days. These preliminary tests indicated that temperatures near 35 C would provide us with a working base from which to further delimit the relations between temperature, salinity, and acclimation time and the effect of these variables on survival time.

During the late spring and summer young-of-the-year menhaden generally are found on nursery grounds where the salinity is 5‰ or less. By fall and winter most young menhaden return to high salinity waters of the lower estuary. In our experiments, acclimation conditions in the tank were controlled so that salinity and temperature were similar to those of the water from which the fish had been collected (Figure 2). The acclimation time varied considerably because we lacked additional acclimation tanks and fish were not always available. The acclimation history is as follows: From the middle of May to the end of August fish were held in water at approximately a 5‰ salinity and a temperature of 20 to 23 C. During October, November, and December fish were held at low (5 to 7‰), medium (15‰) and high (25‰ and greater) salinities and at temperatures between 8 and 25 C. These conditions simulate the ranges which young menhaden encounter in their natural environment. In September we acclimated fish at a salinity of 30‰ and a temperature of 30 C to determine if these acclimation levels had any effect on survival at high test temperatures.

On initiating each experiment we filled the test tanks with water from the acclimation tank so that the 10 young-of-the-year (or 5 yearlings) in each test would not suffer temperature or salinity shock when introduced. The rate of change from acclimation to test temperature was different in the high- and low-temperature tests. In the high-temperature

[1] Trade names referred to in this publication do not imply endorsement.

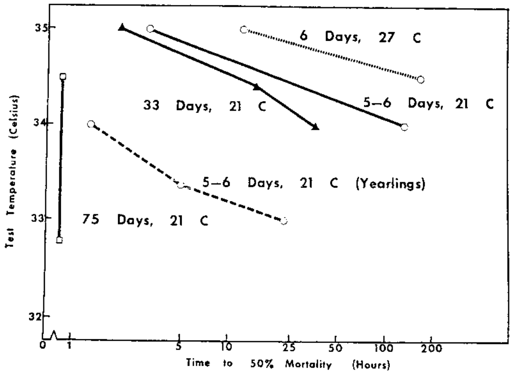

FIGURE 3.—Upper lethal temperature relations for juvenile and yearling Atlantic menhaden. Each point on a line represents one test with 10 young-of-the-year or 5 yearling fish. Resistance time lines for juveniles acclimated to 21 C for 5–6, 33, and 75 days (solid line); young-of-the-year acclimated to 27 C for 6 days (dotted line); and yearlings acclimated to 21 C for 5–6 days (dashed line). Salinity for the acclimation and test periods was 5‰.

tests this change was linear at about 1 degree per hour. In the low-temperature tests it was nonlinear; for example, 2 hours were required to lower the temperature from 18 to 6 C, and 5 hours to lower it from 6 to 4 C. Compressed air bubbled through the water kept the oxygen level in the experimental tanks at about 100% saturation. We continued each test and its control until 50% mortality had occurred or at least 7 days had elapsed.

EFFECTS OF TEMPERATURE AND SALINITY

Young-of-the-year menhaden are very active and difficult to touch with a probe when held at temperatures between 20 and 30 C. At temperatures above 30 C, they swim near the surface with their heads up, gulp air, stop schooling, are less active, and can easily be touched with a probe. With continued exposure they lose stability, start swimming on their sides, settle to the bottom, and occasionally swim in spurts. The amount of swimming decreases progressively. Finally, they lie on the bottom of the tank and flex their opercula at infrequent intervals until death occurs.

Responses in young-of-the-year menhaden were similar at lethal low temperatures to those at high temperatures, although attenuation of breathing spanned a greater amount of time than during high-temperature tests. When held 1 or 2 degrees C below the stress level for 1 week, their body coloration changed from silvery to white.

Results of high-temperature and 5‰ salinity tests revealed that acclimation temperature as well as acclimation time strongly influenced the survival of young-of-the-year (Table 1).

The relations between test temperature and time to 50% mortality were similar for young-of-the-year acclimated from 5 to 21 days, but changed markedly for fish acclimated 33 days (Figure 3). Acclimation of fish for progressively longer periods appeared to reduce survival at each test temperature. Fish acclimated for 75 days survived less than 1 hour at the high test temperatures. When the acclimation temperature was raised from 21 to 27 C and the acclimation time was held uniform at about 6 days, the tolerance of young-of-the-year to high temperatures increased.

In tests run at comparably high temperatures, but at a salinity of 15‰, survival was similar to that in the low-salinity tests (Table 1).

In another series of tests at high temperatures and salinities of 31 to 34‰, survival time was significantly reduced as the test temperature was increased (Table 1). Young-of-the-year menhaden survived longer than 6 days at 34.3 C but only 1-½ days or less at higher temperatures (only a few hours at temperatures above 35.5 C). On the basis of the low-, medium-, and high-salinity tests it appears that salinity is not an important factor in modifying survival at high temperatures.

We also conducted tests with yearling menhaden that had been acclimated at a low salinity (5‰) for 4 to 20 days (Table 2). Fish survived 5 or more days at temperatures below 32 C but only 1 day or less at temperatures above 32.8 C. When fish were acclimated from 5 to 6 days at 21 C, the results indicated that young-of-the-year tolerated higher temperatures than did yearlings (Figure 3).

In late fall, as the water temperature of the natural environment cooled, young-of-the-year menhaden were tested at 3, 4, 5, 6, and 7 C, and at 10 and 26 to 30‰ salinity (Table 3). Acclimation temperature varied between 7.5 and 20.0 C (Figure 2). At 26 to 30‰ salinity,

TABLE 1.—*Results of tests with young-of-the-year Atlantic menhaden subject to high temperature at low, medium, and high salinities*

Test		Acclimation			Hours after start of experiment			
Temperature Celsius	Salinity ‰	Number of hours	Median temperature Celsius	Median salinity ‰	First death	50% survival	Last death	Termination
25.0	5	100–500	22	4	–[1]	–	–	237
30.0	5	100–500	22	4	40	–	–	211
32.0	5	100–500	22	5	–	–	–	154
33.0	5	100–500	21	5	130	–	–	161
33.8	5	>500	21	4	<1	1	2	2
34.0	5	100–500	21	5	12	132	–	161
34.0	5	100–500	27	5	–	–	–	172
34.0	5	100–500	21	4	48	–	–	185
34.0	5	>500	21	4	24	36	107	107
34.2	5	>500	21	4	<1	<2	3	3
34.4	5	>500	21	4	3	15	27	27
34.5	5	100–500	27	5	14	–	–	168
34.5	5	100–500	21	4	46	100	–	168
34.5	5	>500	21	4	<1	<1	3	3
34.5	5	>500	21	4	<1	<1	<1	<1
34.8	5	>500	21	4	<2	<2	3	3
35.0	5	100–500	27	5	10	12	22	22
35.0	5	100–500	21	4	<1	<3	8	8
35.0	5	100–500	21	4	3	<4	6	6
35.0	5	>500	21	4	<1	<1	3	3
35.0	15	<100	24	15	2	<5	7	7
35.5	15	<100	24	15	3	<4	4	4
35.5	15	100–500	24	15	<1	<2	2	2
36.0	15	<100	24	15	<1	<1	1	1
34.3	32	100–500	29	30	–	–	–	158
34.8	32	100–500	29	30	6	32	77	77
35.0	32	100–500	29	30	33	36	85	85
35.2	32	100–500	29	33	7	8	24	24
35.5	34	100–500	29	33	5	8	21	21
35.7	31	100–500	29	32	5	6	8	8
36.0	33	100–500	29	32	3	3	4	4
36.5	31	100–500	29	32	1	<2	2	2

[1] Dashes indicate no deaths.

survival was longer than 5 days at or above 6.0 C, about 2 days at 5.0 C and 1 day or less at or below 4.0 C. At 10‰ salinity fish survived 4 or more days at 5.0 C, and 2 days or less at or below 4.0 C. A comparison between both series of tests indicated that at low temperatures salinity has a limited effect on survival.

The combined results of the tests on young menhaden at high and low temperatures indicated that salinity affects survival less than does temperature. This observation compares with the findings of Lewis (1966) who showed that larval menhaden also have a wide salinity tolerance. Even though menhaden may survive in a wide range of salinities, they probably respond to salinity gradients in an estuary or river that may act as cues to guide them to

TABLE 2.—*Results of tests with yearling Atlantic menhaden subjected to high temperatures at low salinities*

Test		Acclimation			Hours after start of experiment			
Temperature Celsius	Salinity ‰	Number of hours	Median temperature Celsius	Median salinity ‰	First death	50% survival	Last death	Termination
31.0	6	100–500	22	7	40	–[1]	–	136
31.0	6	100–500	22	7	–	–	–	136
31.0	6	100–500	22	7	–	–	–	136
31.5	5	100–500	22	7	82	–	–	130
31.9	5	100–500	22	7	38	73	131	131
32.0	5	100–500	22	7	10	18	87	87
32.8	5	100–500	23	7	4	4	28	28
33.0	5	100–500	23	7	7	23	–	64
33.3	5	100–500	23	7	4	5	28	28
34.0	5	100–500	23	7	<1	2	4	4
34.0	5	100–500	23	7	1	1	4	4
34.0	5	100–500	23	7	1	2	6	6
34.0	4	<100	23	7	<1	<2	4	4
35.0	4	<100	23	7	<1	<1	<1	<1

[1] Dashes indicate no deaths.

TABLE 3.—*Results of tests with young-of-the-year Atlantic menhaden subjected to low temperatures at low and high salinities*

Test		Acclimation			Hours after start of experiment			
Temperature Celsius	Salinity ‰	Number of hours	Median temperature Celsius	Median salinity ‰	First death	50% survival	Last death	Termination
7.0	27	>500	12	28	–[1]	–	–	128
7.0	30	>500	15	28	118	–	–	160
6.0	30	>500	15	28	40	160	–	231
6.0	30	>500	15	28	141	234	–	256
5.0	26	100–500	16	29	39	61	98	98
5.0	26	100–500	16	29	40	53	98	98
4.0	26	100–500	16	29	16	28	37	37
4.0	27	100–500	16	29	3	16	–	21
3.0	27	100–500	16	29	5	10	16	16
3.0	27	100–500	16	29	3	6	11	11
7.0	10	>500	18	10	235	–	–	358
6.0	10	>500	18	10	86	149	–	334
5.0	10	>500	18	10	110	110	–	142
5.0	10	100–500	18	10	128	170	240	240
5.0	10	100–500	18	10	100	114	191	191
4.0	10	>500	18	10	24	27	63	63
4.0	10	100–500	18	10	6	6	99	99
4.0	10	100–500	18	10	23	49	98	98
3.0	10	100–500	18	10	>1	3	49	49
3.0	10	100–500	18	10	0	2	28	28

[1] Dashes indicate no deaths.

and from their nursery areas. McInerney (1964) established that the sequence of changes in preferred salinities paralleled the salinity gradients typical of river outflows through which young salmon pass on their way to the ocean.

The difference in temperature tolerance between young-of-the-year tested in the spring and summer and yearlings tested in the fall cannot be explained by variation in acclimation temperature because both groups of fish were acclimated at similar temperatures (Figure 2). Instead, this difference reflects a developmental change in young menhaden, or a seasonal change regulated by daily photoperiod, or both. Investigations of other species have usually shown that differences in temperature tolerance were associated with a seasonal change rather than a developmental change. For example, preferred temperatures of *Salvelinus fontinalis* (Sullivan and Fisher, 1953) and the thermal resistance of *Carassius auratus* (Hoar, 1955), have been shown to vary seasonally during the year independent of temperature changes or acclimation temperatures. Subsequent tests by Hoar (1956) and Hoar and Robertson (1959) revealed that goldfish reared for short photoperiods were more resistant to low temperatures than those reared at long photoperiods, whereas the reverse was true at high temperatures. Therefore, because we found differences in thermal tolerance between young menhaden tested in spring-summer and in the fall, the observed thermal difference probably reflected a seasonal change in thermal tolerance rather than a physiological change associated with development.

RATE OF TEMPERATURE CHANGE

The rate of temperature change from acclimation to test temperature was examined to determine its effect on survival. In June 1966, 20 fish were tested to determine if young-of-the-year menhaden, acclimated to a salinity of 5‰, could recover from heat stress. The water temperature was raised from the acclimation temperature of 23.0 C (at which the fish had been held 1 month) to 34.8 C in 2 hours. When the fish showed signs of stress at this high temperature, the temperature was lowered in 1 hour to its former level. Six of the 20 fish survived the experiment.

We acclimated another group of 20 fish at 5‰ and 22.5 C $\pm$ 1.0 C for 1 month and then raised the temperature approximately 1 degree per day until it reached 35 C to determine if the rate of temperature change affected survival. Fifty percent of the fish survived 20 hours as compared with 1-½ hours for fish brought to this test level in only 13 hours.

EFFECT OF OXYGEN ON SURVIVAL

Young-of-the-year menhaden were held at 35.5 C, after acclimation for 1 week at 24 C, and tested twice to determine if oxygen concentration affects survival. In the first test, compressed air maintained the test medium at 100% saturation; 5 of the 10 fish survived 1-½ hours. In the second test the oxygen level was kept at 400‰ saturation; half of the fish survived 3 hours. Oxygen concentration apparently can play an important part in controlling survival of young-of-the-year menhaden at high temperatures.

EFFECT OF A PARASITE ON MENHADEN

Olencira praegustator, an isopod, parasitizes both Atlantic menhaden and Gulf menhadens, *Brevoortia patronus* and *B. smithi.* Turner and Roe (1967) reported that most of their parasitized fish contained a single large isopod attached to the anterior roof of the mouth, and that some fish also contained a small isopod attached to the gill filaments. In Albemarle Sound, North Carolina, the incidence of this menhaden parasite is so common that commercial fishermen refer to the fish as "bugmouths."

Turner and Roe (1967) also noted a small amount of gill erosion in some of the fishes but saw no indication that the condition of the host was affected. To determine if the erosion caused by the parasite had any effect on survival time, we conducted two tests with 5 fish each at 34 C to compare survival of unparasitized fish with survival of fish that bore parasites and had erosion of the gills. Gill condition was a factor affecting survival: 50% of the fish with healthy gills survived 2 hours as compared to 1 hour for those with eroded gills.

SUMMARY

The results of the present study revealed that high temperature has a pronounced effect on the survival of young menhaden. Temperatures above 33 C are not uncommon in menhaden nursery areas during the summer and, with more power plants discharging heated waste water, high water temperatures will become an increasing threat to young menhaden.

Acclimation time and temperature, salinity, oxygen level, and gill condition are some of the components that determine how long young menhaden will survive at a particular test temperature, in the laboratory. Test temperatures above 33 C caused death in young menhaden. How soon they die at these high test temperatures depends in part on the levels of the acclimation factors. For example, if the temperature was raised gradually to the test temperature over a period of several days, fish survived longer than if the test temperature was reached in a few hours. This means that if the water temperature in a nursery area increases gradually, menhaden have a better chance to survive than if they are trapped in a discharge of heated water. The condition of the fish and the amount of oxygen present in the water will also determine how long fish survive when subject to adverse thermal conditions.

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